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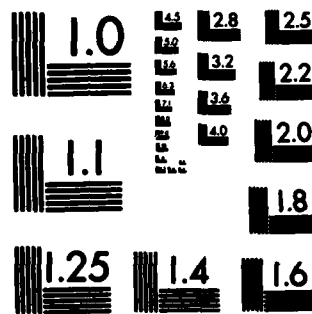UNCLASSIFIED   18 AUG 82 RB3-110 N00014-81-C-0554   F/G 13/2   NL

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A METHODOLOGICAL FRAMEWORK FOR THE ECONOMIC ANALYSIS OF CURTAIN BARRIER SEDIMENTATION CONTROL SYSTEMS

By

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AND
NAVAL FACILITIES ENGINEERING COMMAND

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OF CURTAIN BARRIER SEDIMENTATION CONTROL SYSTEMS

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for

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INTRODUCTION

The Office of Naval Research and the Naval Facilities Engineering Command have been sponsoring research in the area of dredging and sedimentation control for over a decade. One promising concept that is currently being examined for reducing sediment accumulation in enclosed, quiet-water berths is passive denial by use of curtain barriers. In its most simplistic form, a sediment-impermeable membrane is placed across the entrance to the berthing area, thus forcing sediment-ladened water to remain in the channel/harbor area and denying it access to the quiet-water berth. Although individual designs may differ in implementation details, e.g., full height vs partial height, methods for opening and closing to permit ship access, etc., the basic notion is still the same. Given that the engineering details for a given application site can be resolved (not always a trivial matter), there appears to be a need to be able to determine, from an economic basis, which particular sites offer the greatest potential and which do not appear promising from economic consideration. In short, there is a need for an economic screening method that can be used to determine potential application sites for curtain barriers at Navy berths.

This report presents such an economic screening method, identifying those variables to which decisions are most sensitive, and illustrates the use of the method by applying it to selected Naval berthing areas.

APPROACH

Since one solution to sediment accumulation is simply maintenance dredging, one might be tempted to view its cost as the basis against which to compare any alternative under consideration. While this is true to a certain extent, it is a bit simplistic in reality. One reason is that, simply because a berth has silted in, it is not necessarily dredged immediately. "Thick water" may be endured for a while until the overall dredging requirement is large enough to justify dredge mobilization costs. The cost of this mission impairment is difficult to quantify, but it should be added to the actual dredging cost in order to obtain a more accurate comparison. Estimating such costs is, however, beyond the scope of the present analytical effort. A second reason is reflected in the allocation of costs for a dredging project. The dredging of a sheltered berth is more tedious and time consuming than open harbor or channel dredging

due to waterfront structures and space confinements. Dredging costs, however, do not normally reflect such real differences and are usually stated as averages for the entire dredging project. This factor can be accounted for in the screening method presented herein. With the foregoing caveats, what follows is a methodology for determining the cost effectiveness of curtain barriers as opposed to conventional dredging practices.

Agreement is lacking on a single measure of cost effectiveness that will serve the present effort. Original goals were stated in terms of percent savings which, although easy to understand, do not reflect opportunity costs such as the cost of money and, therefore, are considered here to be less desirable than other measures. The savings investment ratio is a popular economic comparison measure being used for projects, but its value is highly dependent upon project life, which is not well known as yet for curtain barriers. A third measure is the payback period. Although closely related to the savings investment ratio, the payback period calculation does not explicitly involve project life -- if the project life can be reasonably expected to exceed the payback period, a positive benefit is indicated, although its final magnitude is not determined. Since the cost of money is taken into account in payback period calculations, it is recommended as the best single economic comparison measure for curtain barriers at the present time, and its use is emphasized in the screening method-ology presented below. However, overall percent savings on an annual basis and savings investment ratios are also presented, despite their drawbacks, to provide a more complete treatment.

The expressions for annual percent savings (σ), savings investment ratio (SIR), and payback period (n') are derived in the appendix and can be written as:

$$\frac{\sigma}{100} = \eta - \frac{m + c/n}{d \cdot f} \qquad (I)$$

$$SIR = \frac{n \cdot d \cdot f - m}{c} \left[\frac{(1.1)^n - 1}{0.1 \, (1.1)^n} \right] \qquad (II)$$

$$n = -10.492 \ln \left(1 - \frac{0.1c}{n \cdot d \cdot f - m}\right) \qquad (III)$$

where η is the effectiveness (or efficiency) of the curtain barrier expressed as a decimal, m is the annual operation and maintenance cost of the curtain

expressed on a per foot basis, c is the capital cost of the curtain per foot, d is the unit cost of dredging (say dollars per cubic yard), n is the expected curtain life in years, and f is the sedimentation flux density in the berth per foot of curtain (expressed, for example, as cubic yards per year per foot of curtain). Of course ln indicates the natural logarithm.

Of the variables contained in the above three expressions, only f (and d to a lesser extent) should be highly site specific, and it is therefore the logical parameter to use in initially screening candidate sites for possible curtain application. For example, early in the development of curtain barriers by the Navy it was estimated that curtain effectiveness should be 80% or better ($\eta = 0.8$), that curtain life should be five years or longer ($n = 5$), that curtain cost (c) should be $400 per foot or less, that average berth dredging costs (d) would be $3 per cubic yard, and operation and maintenance costs were almost negligible ($m = 0$). In such a case, the foregoing expressions become:

$$\frac{\sigma}{100} = 0.8 - 26.7/f$$

$$SIR = f/44$$

$$\eta' = -10.5 \ln (1 - 16.7/f)$$

Here it can be seen that, for curtain barrier projects to be cost effective, they should only be installed at berths for which $f \geq 44$, below which value SIR <1 and η' >5 years giving no real economic benefit, even though $\sigma = 19.3\%$ (recall that the calculation for σ does not account for the cost of money).

An examination of values of f for different Navy harbor areas appears in order. They are presented for areas within six Naval harbors in Table 1. As can be noted, they range from a low of around 20 at Philadelphia to a high of over 1,700 at Mayport. If one takes $f \geq 50$ as a quick screening criteria, it is seen that most piers at Norfolk and all but the reserve basin at Philadelphia are unlikely candidates for curtain barriers from an economic standpoint. One should be cautioned not to assume that the other sites are curtain candidates -- many physical factors must be considered as well. For example, the sedimentation problem at Mayport is due to a hydrostatic instability during portions of the tidal cycle, and a venting canal is the more logical solution approach.

Table 1. Representative Sedimentation Flux Density Values per

Foot of Curtain (yd^3/yr·ft)

CHARLESTON		NORFOLK	
Piers C-D,	244	Pier 12N,	37
" D-F,	265	" 12S,	47
" F-G,	128	" 10-7,	185
" G-H,	101	" 7-5,	62
" H-J,	97	" 5-4,	52
" J-K,	149	" 4-3,	49
" K-L,	203	" 3-2,	49
" L-M,	174	" 23-22,	52
" M-N,	231	" 22-21,	55
" N-P,	207	" 21-20,	49
" P-Q,	138		
" Q-R,	143	PHILADELPHIA	
" R-S,	83	Res. Basin,	302
" S-T,	81	Piers 6-5,	20
" T-V,	87	" 5-4,	25
		" 4-2,	26

ALAMEDA	MARE ISLAND	
Breakwater Gap, 295	Berth 20-21N,	336
	" 215-22N,	336
MAYPORT	" 225-23N,	336
Wards Bank, 1,752	" 235- 2A,	336

The harbors used in Table 1 are illustrative only, simply being those for which the writer had data (provided by the Naval Civil Engineering Laboratory) from which f-values could be calculated.

Although the foregoing is useful in providing an initial sense of the proposed methodology, an investigation of the sensitivity of the economic effectiveness measurands to variations in the parameters is warranted. The table below is considered to provide a realistic range for each of the involved variables.

	low	medium	high
η (%/100)	0.5	0.75	0.90
c ($/ft)	200	400	800
n (yrs)	2.5	5	10
m ($/ft·yr)	30	60	120
d ($/yd^3)	1.5	3	6

The results of the sensitivity analysis are given in Table 2, where an underline is used to indicate values that are economically undesirable. As can be noted from Table 2, the larger the value of f, the less the relative impact of the other parameter values. In fact, for f = 100 conditions are generally favorable economically (except for the lowest value of the parameter being varied in most instances), and for f = 200 conditions are always favorable. As can also be seen, results are relatively insensitive to changes in operation and maintenance costs (m) and are most sensitive to unit dredging costs (d).

As stated earlier, the payback period is at this time the recommended economic performance measure for screening analyses since it is independent of curtain life. If we arbitrarily set an acceptable payback period to be three years (i.e., n' = 3) and solve equation (III) for f, we obtain;

$$ f = \frac{m + 0.4c}{\eta \cdot d} \qquad (IV) $$

which we shall use to graphically portray the impact of curtain effectiveness (η), curtain capital cost per foot (c), and annual operation and maintenance cost per foot of curtain (m) on the required f-value for different unit dredging costs (d). It should be pointed out in passing that if one takes a project life

Table 2. Sensitivity Analysis Results

	σ			SIR			n'		
f/η	0.50	0.75	0.90	0.50	0.75	0.90	0.50	0.75	0.90
50	– 43	– 18	– 3	.14	.50	.71	–	15.1	8.0
100	3	28	43	.85	1.56	1.99	6.2	2.9	2.2
200	27	52	67	2.27	3.70	4.55	1.9	1.1	.9
f/c	200	400	800	200	400	800	200	400	800
50	8	– 18	– 72	1.00	.50	.25	5.0	15.1	–
100	42	28	2	3.13	1.56	.78	1.4	2.9	7.0
200	58	52	38	7.39	3.70	1.85	.6	1.1	2.4
f/n	2.5	5	10	2.5	5	10	2.5	5	10
50	– 72	– 18	8	.28	.50	.81	15.1	15.1	15.1
100	2	28	42	.87	1.56	2.53	2.9	2.9	2.9
200	38	52	58	2.07	3.70	5.99	1.1	1.1	1.1
f/m	30	60	120	30	60	120	30	60	120
50	2	– 18	– 58	.78	.50	.07	6.9	15.1	19.4
100	38	28	8	1.85	1.56	1.00	2.4	2.9	5.0
200	57	52	42	3.98	3.70	3.13	1.1	1.1	1.4
f/d	1.5	3	6	1.5	3	6	1.5	3	6
50	-112	– 18	28	-.04	.50	1.56	–	15.1	2.9
100	– 18	28	52	.50	1.56	3.70	15.1	2.9	1.1
200	28	52	63	1.56	3.70	7.96	2.9	1.1	.5

of five years and seeks a savings investment ratio of 1.5 or greater, equation (II) reduces to equation (IV) also.

The impact of curtain effectiveness is depicted in Figure 1, where we have taken curtain capital costs to be four hundred dollars per foot (c = 400) and O&M cost to be sixty dollars per year per foot of curtain (m = 60). As can be seen, very high f-values are required for unit dredging costs under $1.50 per cubic yard, even for near 100% curtain effectiveness. On the other hand, if curtain effectiveness is around 80%, unit dredging costs must exceed $2.75 per cubic yard before berthing areas with f-values less than 100 will be economically viable candidates.

The effect of curtain capital cost on the required f-value for a candidate site is depicted in Figure 2, where we have taken curtain effectiveness to be 80% (η = 0.8) and kept O&M costs at sixty dollars per year per foot of curtain. Here it can be seen that for unit dredging costs of $3 per cubic yard and higher, the cost of the curtain has relatively little impact on the required f-value. Very large increases in curtain cost produce rather modest increases in the required f-value. For example, if the unit dredging cost is $3 per cubic yard, doubling the curtain cost from $210 per foot to $420 per foot only increases the required f-value from 60 to 95.

The effect of annual operation and maintenance cost on the required f-value for a candidate site is depicted in Figure 3, where we have taken curtain effectiveness to be 80% (η = 0.8) and curtain cost to be four hundred dollars per foot (c = 400). As can be seen from the very shallow slopes for unit dredging costs of around $1.50 per cubic yard and up, very large increases in O&M costs are necessary to cause an appreciable increase in the required f-value.

As mentioned earlier, the payback period expression does not contain the expected project life. To see the effect of project life on required f-values it is necessary to take equation (II) and solve it for f. Again taking η = 0.8, c = 400, m = 60, and requiring a savings investment ratio of at least 1.5, we obtain;

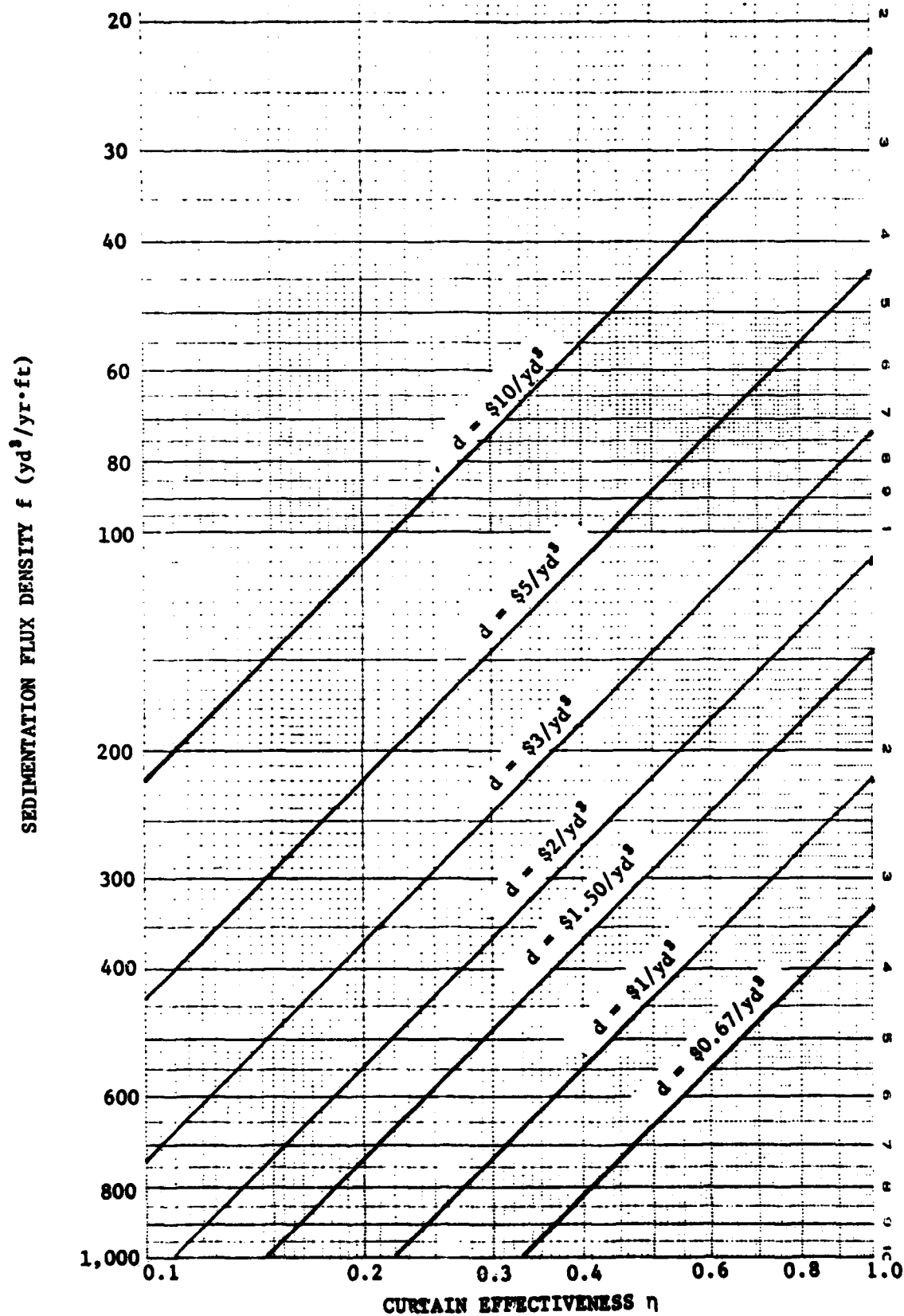$$f = \frac{150 - 75 \, (1.1)^{-n}}{d[1-(1.1)^{-n}]} \qquad \text{(V)}$$

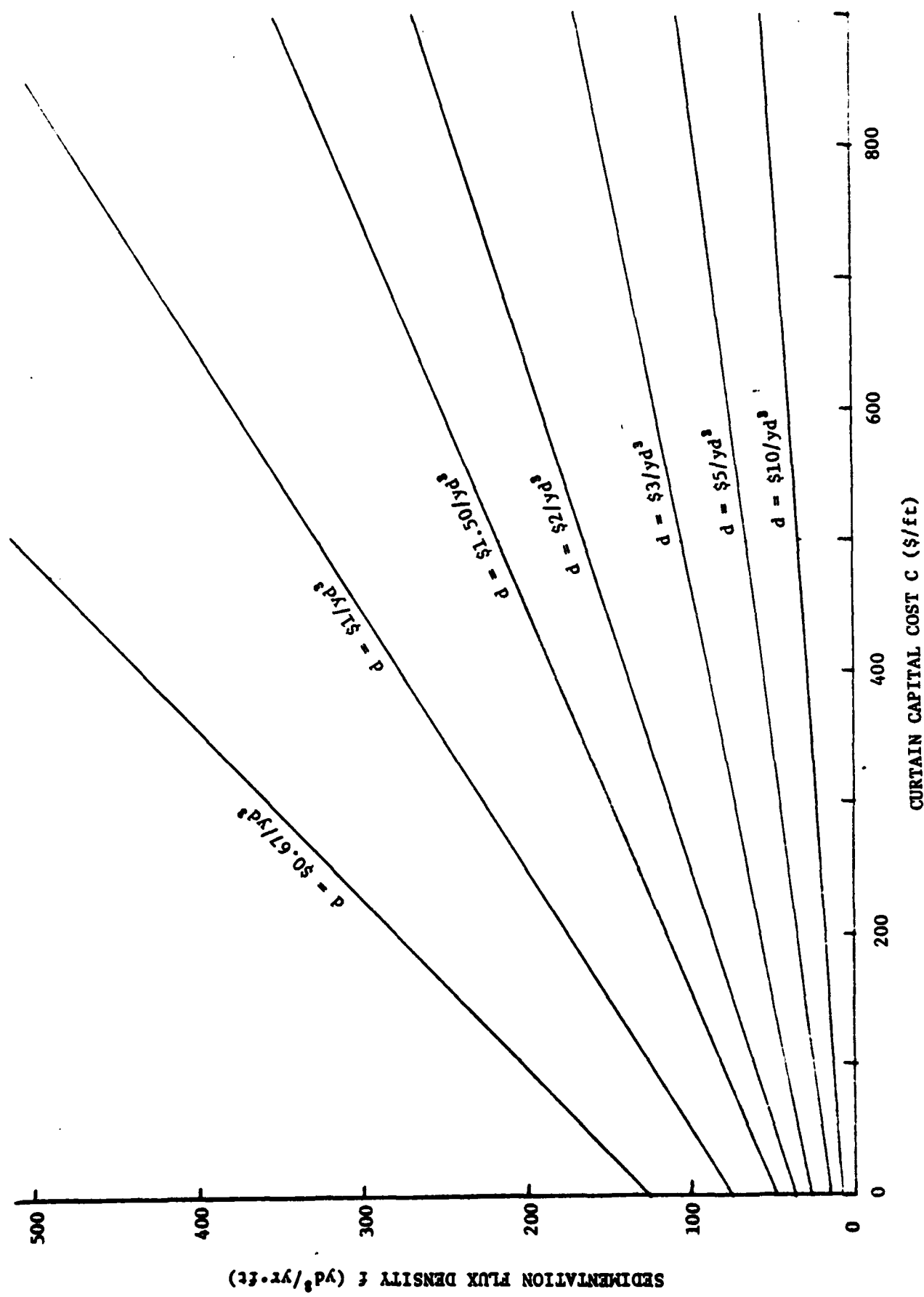Figure 1. Impact of Curtain Effectiveness on Required f-Value

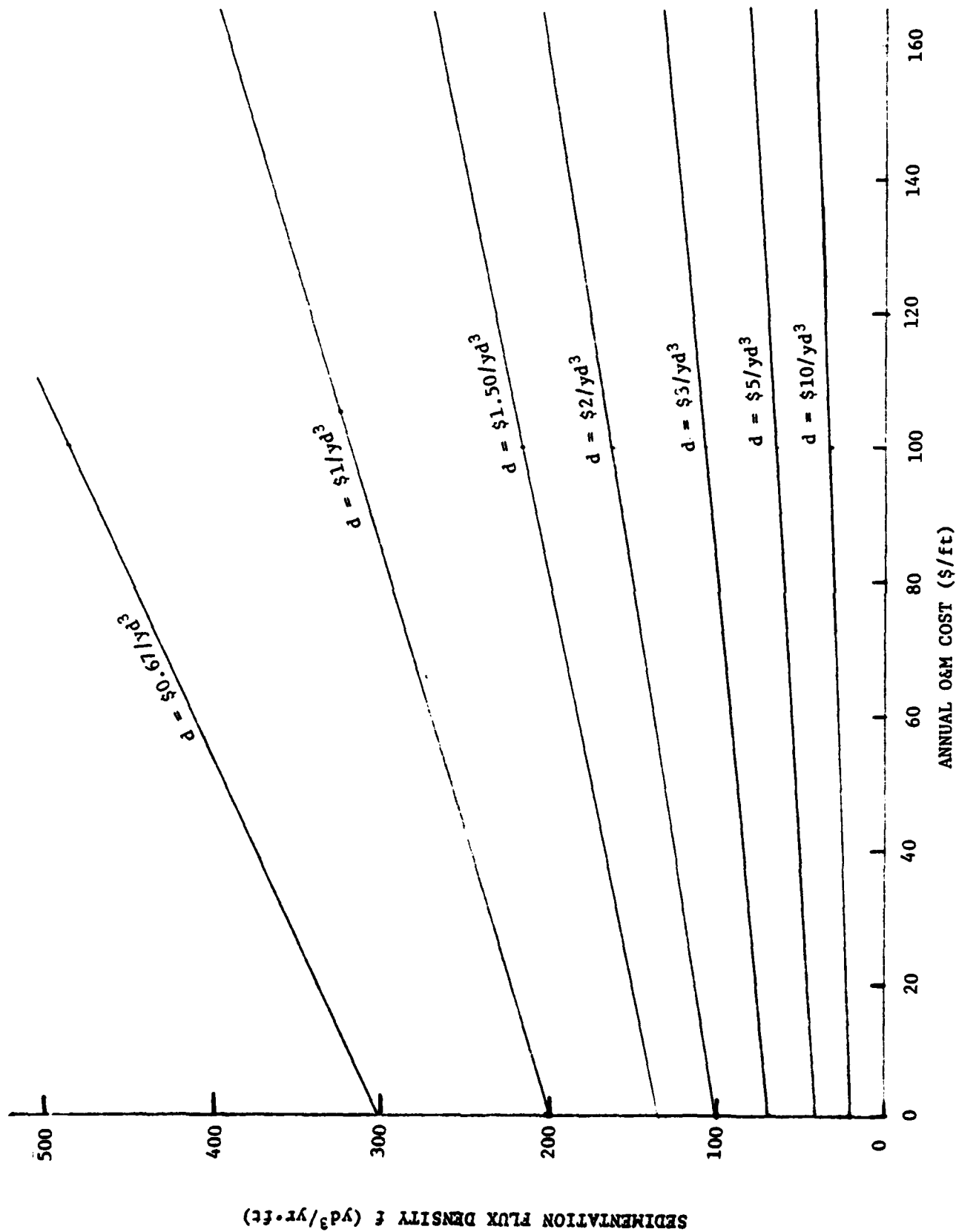Figure 2. Impact of Curtain Capital Cost on Required f-Value

Figure 3. Impact of Annual O&M Cost on Required f-Value

Equation (V) is depicted in Figure 4, where it can be seen that, for any given unit dredging cost, great increases in curtain life are necessary after around five years in order to reduce the required f-value appreciably.

It has been shown how to utilize the methodological framework presented herein as a screening tool to aid in candidate site assessment from economic considerations. It should be obvious, however, that the basic approach can be used for other purposes also, conducting design trade-offs for example. Consider the design question wherein one is interested in the trade-off between reducing annual operation and maintenance cost by upgrading the curtain design with an attendent increase in initial capital cost. In such a case we can use equation (IV) and make the plots shown in Figure 5.

Looking at Figure 5, consider the case where $\eta = 0.8$, $d = 3$, and $f = 125$, so $\eta \cdot d \cdot f = 300$. We move along that line to note that if our comparative baseline curtain capital cost is $500 per foot with an O&M cost of $100 per year per foot, we could only afford a 25% increase in initial curtain cost (to $625/ft) to achieve a 50% reduction in O&M cost (to $50/yr.ft). On the other hand, if we halve the cost of the curtain (to $250/ft), we could afford to double the annual O&M cost (to $200/yr.ft). Conclusions can be reached for other values of the product $\eta \cdot d \cdot f$ in a similar fashion.

On the other hand, consider the design question where one is interested in the trade-off between initial curtain cost and curtain life. In this case we can use a variant of equation (V) and construct the plots shown in Figure 6. Again considering the case where $\eta \cdot d \cdot f = 300$, we see that we could afford to increase curtain cost from around $400 per foot to $700 per foot, a 75% increase, to double the expected curtain life from 3 years to 6 years. To triple the expected life to 9 years would require a 130% increase in curtain cost to $925 per foot, while reducing the curtain life by 50% to 2 years could be accomplished at a 30% reduction in curtain cost to $278 per foot.

The foregoing design question examples are not meant to be exhaustive but, rather, to be suggestive of some of the other ways that the methodological framework presented herein can be used in examining curtain barrier approaches to reduction of sedimentation costs in quiet water berths.
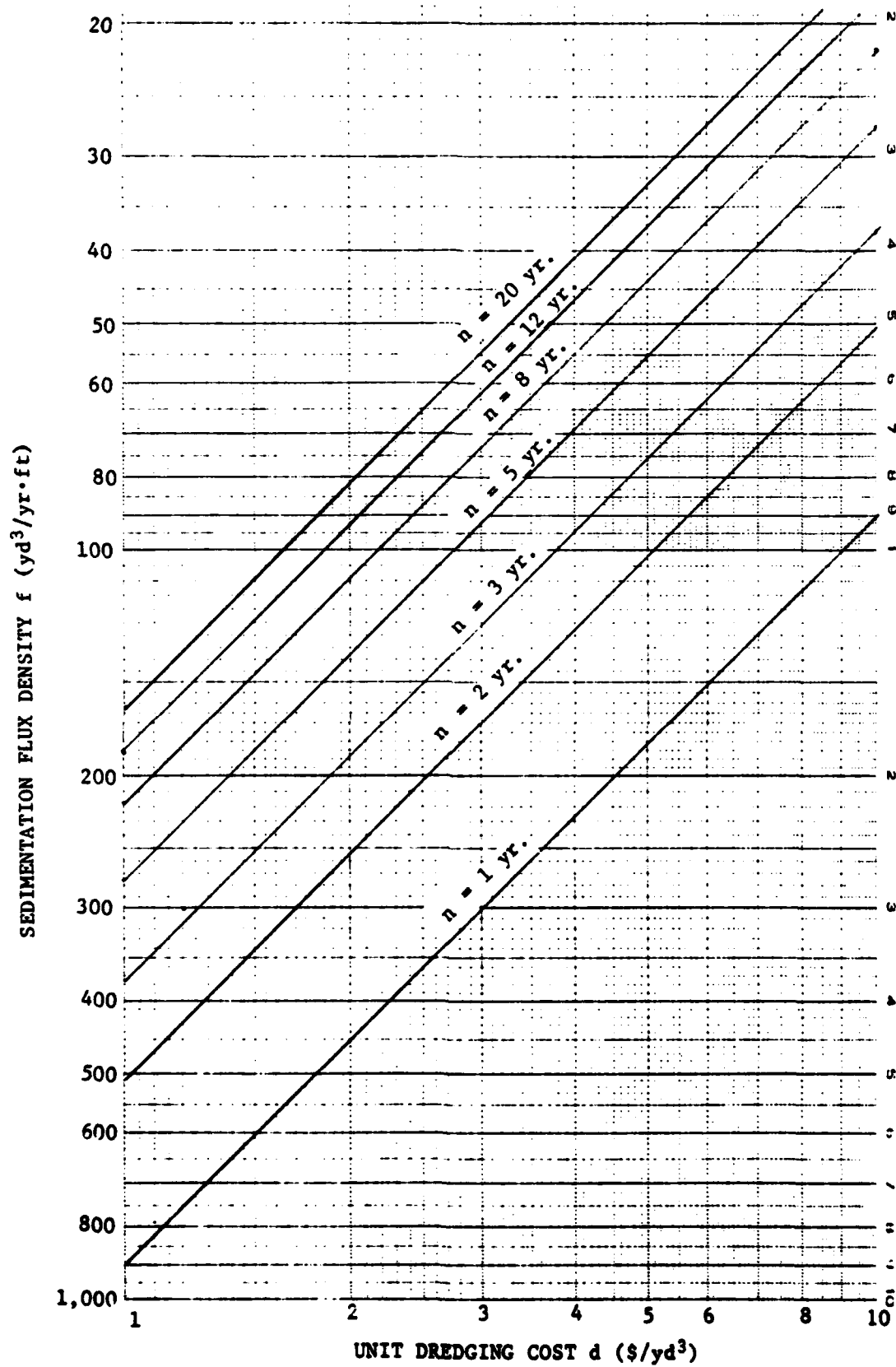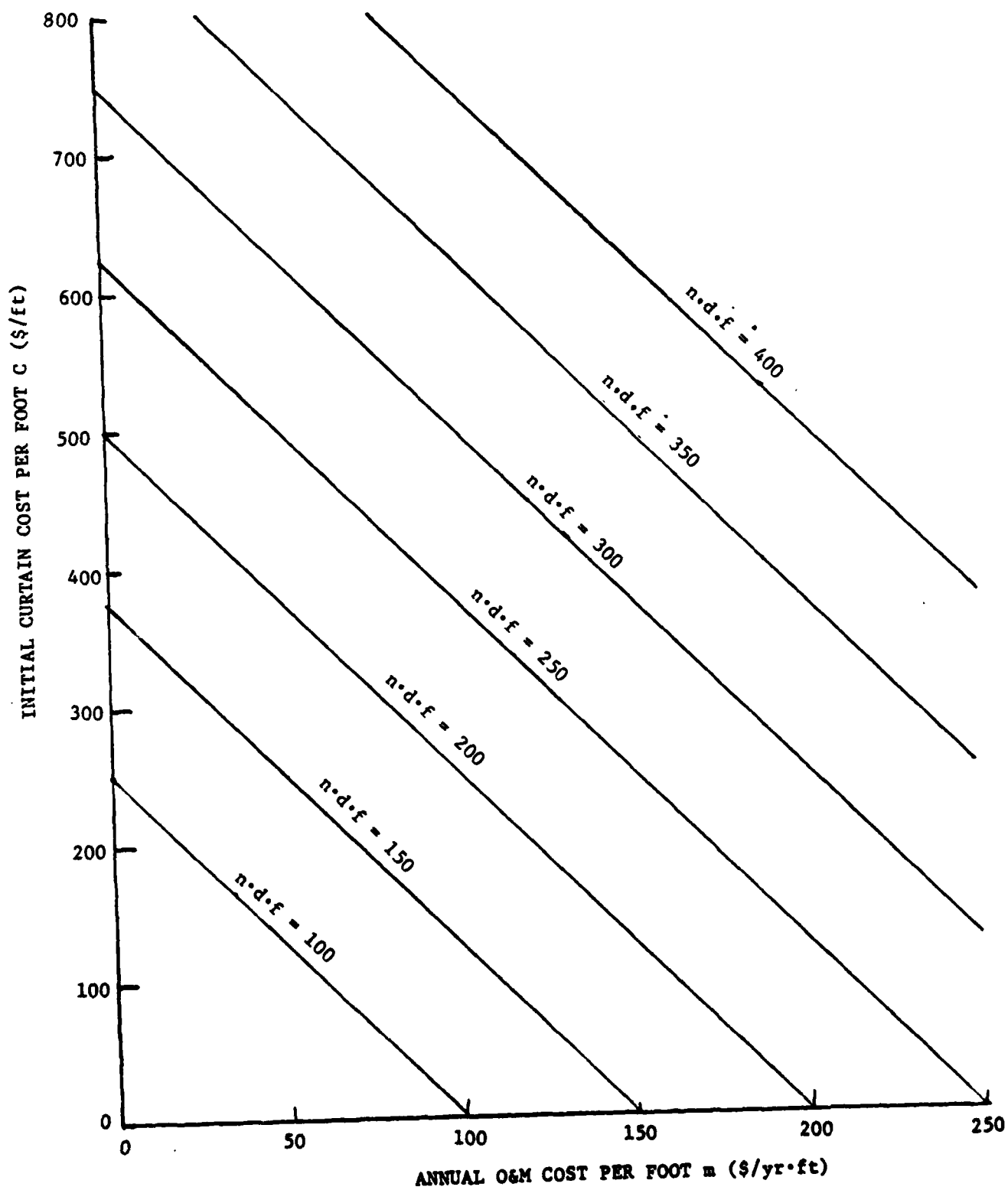
Figure 4. Effect of Curtain Life on Required f-Value
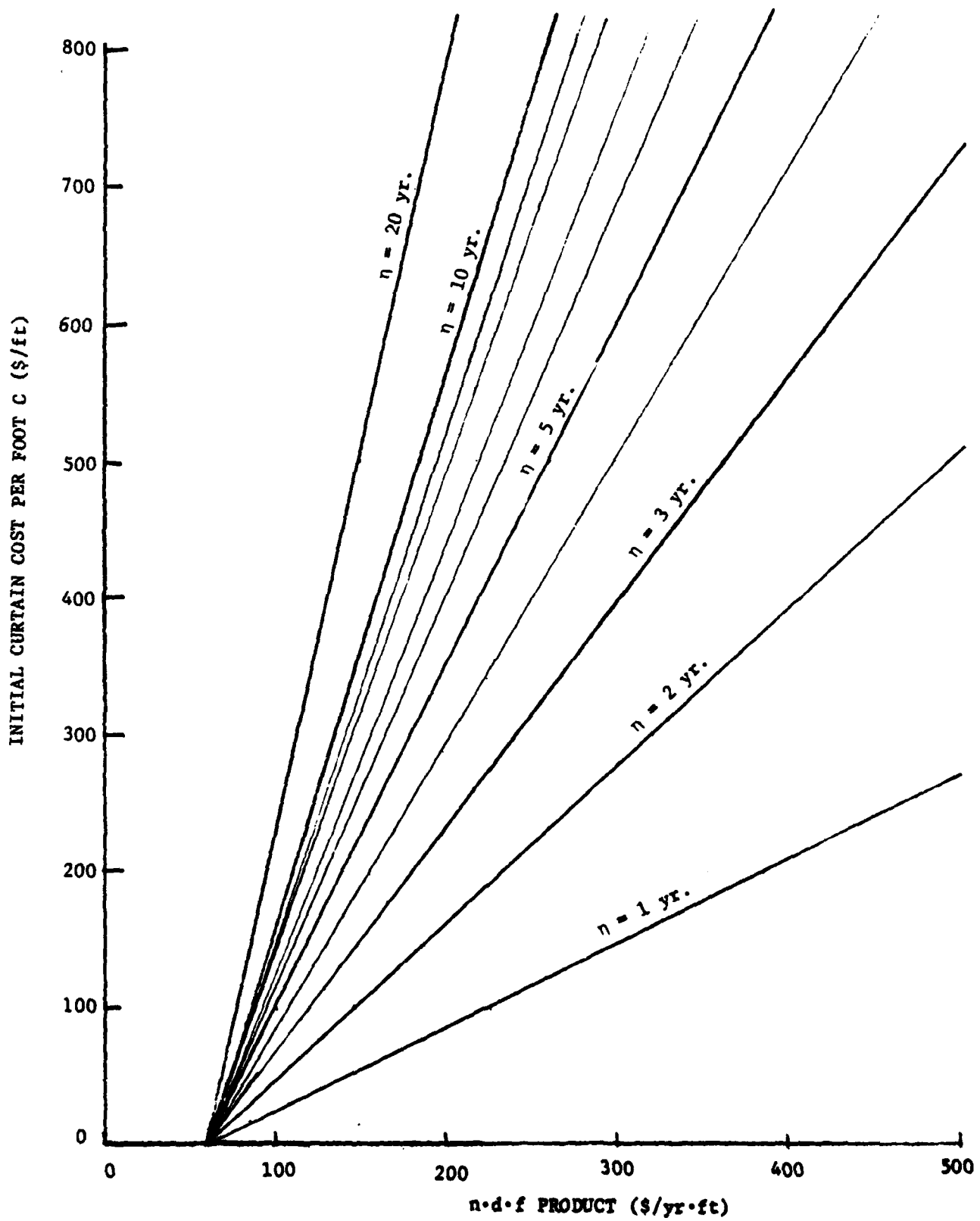
Figure 5. Curtain Capital vs O&M Cost

Figure 6. Curtain Capital Cost vs Life

NOTATION

a	area protected per foot of curtain (yd^2)
A	annual gross savings ($/yr)
c	capital cost of curtain per foot ($/ft)
d	unit dredging cost ($/$yd^3$)
D	annualized dredging cost without curtain ($/yr)
D'	annualized dredging cost with curtain ($/yr)
f	sedimentation flux density per foot of curtain ($f = a \cdot r/3$) (Yd^3/yr·ft)
i	discount rate
L	curtain length (ft)
m	annual curtain operation and maintenance cost per foot ($/ft·yr)
M	annual curtain O&M cost ($/yr)
n	expected curtain life (years)
n'	payback period (years)
N	annual net savings ($/yr)
PV	present value factor
r	sedimentation rate in berth (ft/yr)
SIR	savings investment ratio
η	curtain effectiveness (efficiency)
σ	percent savings

APPENDIX

DERIVATIONS

We begin by noting that the total area protected by the curtain is $a \cdot L$ and that the average annual sediment accummulation is $f \cdot L = r \cdot a \cdot L/3$, so the annualized dredging cost without and with the curtain can be expressed respectively as;

$$D = d \cdot f \cdot L \qquad (1a)$$

$$D' = (1 - n) D + M \qquad (1b)$$

The average annual gross savings (A) is simply D-D' and, using equations (1), can be expressed as;

$$A = \eta \cdot d \cdot f \cdot L - M \qquad (2)$$

Without consideration of opportunity costs, the average annual net savings (N) is the gross savings less the annualized capital cost of the curtain, which can be expressed as;

$$N = A - c \cdot L/n \qquad (3)$$

Therefore, the average annual percent savings (σ) expressed as a decimal is;

$$\sigma = N/D \qquad (4)$$

Substituting from equations (1a), (2), and (3), we obtain;

$$\sigma = \eta - \frac{M + C/n}{d \cdot f} \qquad (I)$$

The present value of a series of uniform annual costs over a period of n years is calculated by multiplying the annual recurring cost by the present value factor (PV);

$$PV = \frac{(1 + i)^n - 1}{i(1 + i)^n} \qquad (5)$$

where i is the discount rate. The savings investment ratio (SIR) of a project is the present value of the gross savings over the life of the project divided by its capitol cost, or;

$$SIR = PV \cdot A/c \cdot L \qquad (6)$$

Substituting from equation (2) and (5), and taking the discount rate to be 10% in accordance with NFAC P-422, we obtain;

$$SIR = \frac{n \cdot d \cdot f - m}{c} \left[\frac{(1.1)^n - 1}{0.1(1.1)^n} \right] \qquad (II)$$

The payback period (n') for a project is the number of years until the present value of the gross savings is equal to the capitol cost; that is when

$$PV \cdot A = C \cdot L \qquad (7)$$

Substituting from equations (2) and (5) with n' replacing n and again using a 10% discount rate, we solve for n' and obtain;

$$n' = -10.492 \ln \left(1 - \frac{0.1c}{n \cdot d \cdot f - m} \right) \qquad (III)$$

It scarcely needs pointing out that the payback period is that point in time when the savings investment ratio equals unity.

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